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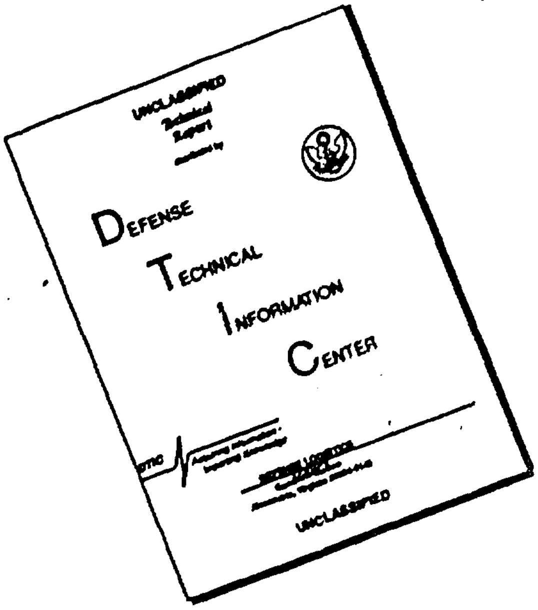

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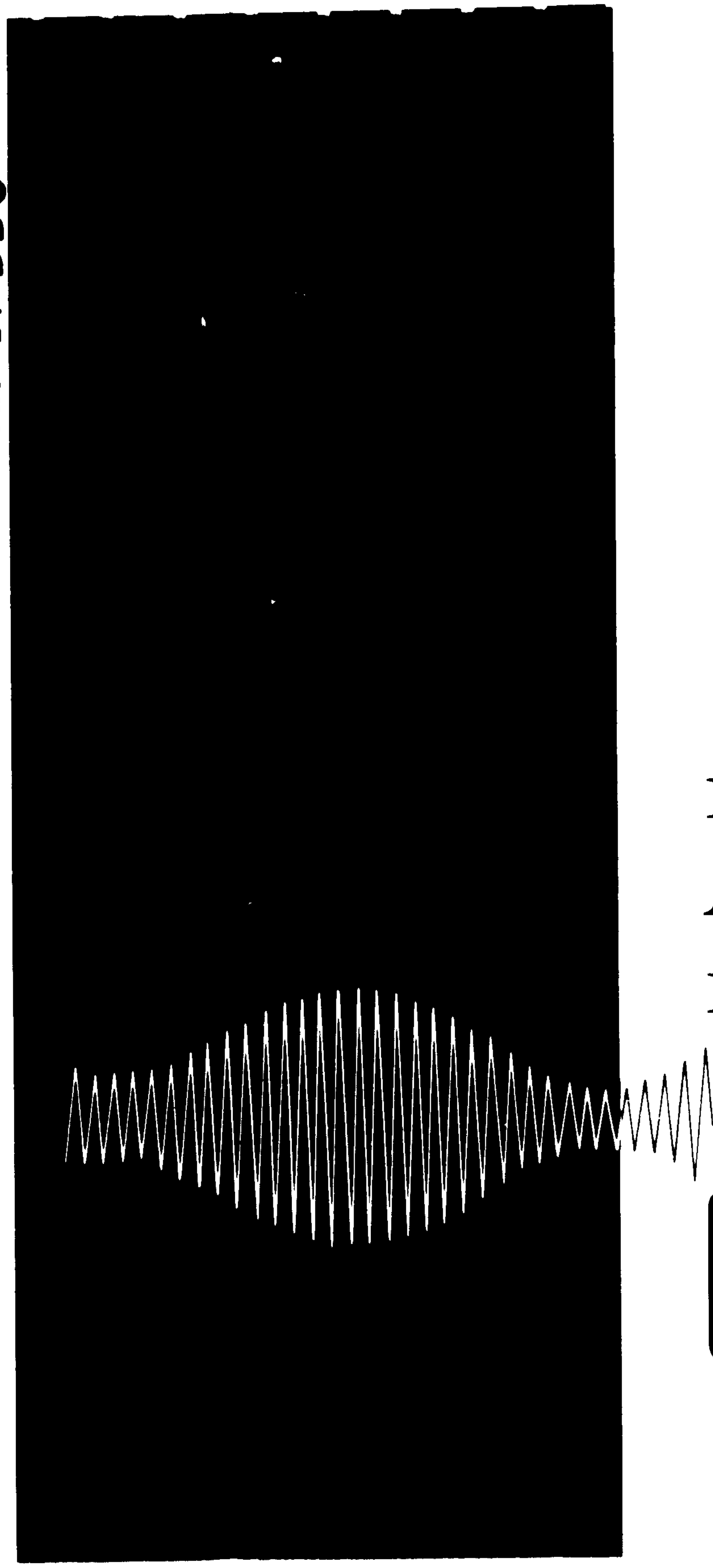

LONG LIFE K-BAND DUPLEXER

Report No. 3

Contract No. DA-36-039-SC-90834

Project No. ARDS-A-142

Third Quarterly Technical Report

1 December 1962 - 1 April 1963

U.S. Army Electronics Research
And Development Laboratory
Fort Monmouth, New Jersey

MICROWAVE ASSOCIATES, INC.
BURLINGTON, MASSACHUSETTS

MICROWAVE
ASSOCIATES,
INC.

LONG LIFE K-BAND DUPLEXER

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Contract No. DA-36-039-SC-90834

Electronics Command Technical Requirements No. SCL-5837B June 6, 1961

Amendment No. 2, April 4, 1962

Project No. ARDS-A-142

Third Quarterly Technical Report

1 December 1962 - 1 April 1963

Prepared by:

R. Brunton

Approved by:

R. Tenenholtz

MICROWAVE ASSOCIATES, INC.

BURLINGTON, MASSACHUSETTS

May 7, 1963

"The work prepared under this contract was made possible by the support of the Federal Aviation Agency, Aviation Research and Development Service, Washington, D.C., through the United States Army Electronics Research and Development Laboratory."

TABLE OF CONTENTS

I PURPOSE

The purpose of this contract is to develop a long life K-band three-port duplexer exhibiting extremely low leakage power characteristics. Pertinent desired operation characteristics are as follows:

Frequency:	23.5 - 24.5 KMc
Peak Power:	100 KW
Pulse Width:	0.020 μs
Duty Cycle:	.003
Leakage Power, Spike:	.075 ergs
Leakage Power, Flat:	40 mw
Recovery Time:	0.050 μs
Life:	5000 Hours
Insertion Loss: (low level)	1.0 db max.

In addition, VSWR, and environmental specifications as called for in Electronics Command Technical Requirement SCL - 5837 B must be met.

RE: Units On QR.

The technical work on this contract has been divided into six major tasks. Each task will design and develop a device applicable toward the specifications of the contract. Each task is listed below with a brief description of the technical task.

Task I Ferrite Circulator

A Ferrite Circulator will be designed for application in a long life duplexer where an RF high power limiter will also incorporated.

Task II Ferrite Limiter Development

A ferrite limiter design and development will be carried out to meet the requirements of the contract specifications in conjunction with the ferrite circulator.

Task III Gas TR Tube Development

A long life gas TR tube design and development task will be initiated where no keep-alive voltage will be required and the design goal will be toward a limiter applicable to the contract specifications.

Task IV Multipactor Limiter Development

A multipactor limiter design and development program will investigate design and fabricate a limiter device in which the goals are for application in the contract duplexer requirements.

Task V Semiconductor Switch Limiter Development

A semiconductor limiter will be designed for high power limiting to use in conjunction with the ferrite circulator for a long life duplexer.

Each of the above tasks are separate investigations and at a pre-arranged point in the contract, these tasks will be reviewed and the final limiter design approach will be determined.

Task VI Packaging of the Final Duplexer Desgin

The duplexer packaging will be arranged for substitution directly into existing radar systems, without modification of the systems other than to remove the existing duplexer.

II ABSTRACT

During the third quarterly period of this contract, technical activities on the long life gas TR tube, semiconductor switch limiter and ferrite limiter resulted in experimental models and test data.

The gas TR tube has been measured at an incident power of 3.6 KW without keep alive, the spike energy was 2. ergs and the flat power 75 milliwatts.

The semiconductor switch limiter efforts were successful when a PIN diode was used in the ridged waveguide test fixture. With DC bias a switch was operated from 22 to 24.5 GC with an insertion loss of 1.4 db maximum and an isolation of 28.4 db minimum, the power level was 1 milliwatt. The same device was measured in the forward bias state (high isolation) at 1.KW incident power where the isolation was measured to be 30 db or greater.

A ferrite limiter was measured with limiting in excess of 16 db. The insertion loss was 4 to 6. db.

Preliminary multipactor units have been constructed to test surface and multipacting however test data has not been obtained.

V

PUBLICATION, LECTURES, REPORTS & CONFERENCES

During this contract period a meeting was held between the following persons at Microwave Associates:

Mr. Wright	Signal Corps
Mr. Goldman	FAA
Mr. Tenenholtz	Microwave Associates
Mr. Brunton	" "
Dr. M. Gilden	" "
Mr. Basken	" "

A brief discussion of the contract expenditures and general technical progress was held prior to demonstration and examination of hardware developed to date. The engineers responsible for each technical task were visited and Mr. Wright and Mr. Goldman were given an opportunity to discuss technical details.

The technical information discussed is recorded throughout the report therefore a detailed review will not be written in this section.

There have been no Publications reports lectures or Conferences pretaining to this contract during this period.

4.1 K-Band Long Life Gas TR

During this quarter, three TR tubes were fabricated and tested. Tube No. K1 was designed with two windows ($Q_w = 3$), a single gap with a Q of 6, and a 240 degree spacing between elements. The bandpass of this tube was 9 per cent, the insertion loss varied from .4 to .55 db due to the relatively high Q center element. This is illustrated in Figure 1. Since the bandpass requirement is one half the amount achieved with tube No. K1, it was considered advisable to lower the center element Q in a subsequent model. The window Q was left unchanged, a decrease in bandpass resulted and the insertion loss improved. Figure 2 is a plot of the VSWR and insertion loss of tube No. 010 which consisted of two windows of Q = 3 spaced 240 degrees from a center element of 3.8. The insertion loss varies from .3 to .4 db for the unplated tube, with plating the loss is usually lowered another .05 to .1 db.

A third tube of similar design to No. 010 was fabricated and was not exhausted. This unit was used for a spark gap experiment to determine the RF breakdown in air, which occured at 12 kilowatts.

Tubes No. K1 and 010 were provided with keep alives for the purpose of securing accurate breakdown measurements, since it is difficult at lower pulse repetition rates to achieve consistent and repeatable gap breakdown if no keep alive discharge is present to prime the gap. The high level tests indicated, however, that the 15 Kc repetition rate was fast enough to obtain low and consistent breakdown values without the keep-alive on.

The extremely fast transients associated with the gap breakdown were measured with a high speed sampling scope. The incident pulse, as viewed with the sampling scope, had a shape as drawn in Figure 3. High power measurement results on tube K1 and 010 are summarized in Figure 4, Table 1. With an incident peak power of 3.6 KW, the amplitude and width of the spike were measured with keep-alive off and on. The method was counter checked by a determination of the average leakage with a thermistor and power bridge. The flat leakage power was measured by the conventional scope method.

Test results indicate, as predicted, that the tube with lower center element Q (No. 010) had higher spike energy than tube No. K1 and the difference was less pronounced with no keep-alive. It is noteworthy to observe the close correlation between scope and bridge measurements. As indicated above, the spike pulse was very stable even without keep-alive current. No random spikes of excessive energy were observed. This is of particular significance, since tests have indicated that the keep-alive is the ultimate limitation in life expectancy of a gas discharge device. The two-erg spike, although far too high for a sensitive receiver diode, should present no problem to a semiconductor limiter following the TR.

Figure 5 is a graphical presentation of the incident and leakage pulse envelopes. Care must be taken in interpreting the various power values on semi-logarithmic paper, since the higher power regions are compressed. From this figure, it can be seen that the isolation achieved

by the gap alone - just before the window breakdown - is about 30 db, and the total isolation of the gap and window combined is nearly 50 db, allowing about 75 MW of flat leakage power to pass during the pulse. The region labeled "pseudo - flat" is simply the leakage in the time between gap and window breakdown, and is of relatively short duration (3 nanoseconds).

Recovery time of both tubes was also measured and recorded in Figure 4, Table 1. As the recovery time is inversely proportional to the spike leakage energy, any change in gasfill to reduce the recovery time significantly below the 200 nanoseconds will raise the spike energy considerable.

In summary, the tube design effort has been successful. Two more units of this design are presently being fabricated, and life tests will be started during the next quarterly period.

4.2 Semiconductor Limiter

Efforts on the design of limiters using packaged PIN diodes has been discontinued. The parasitic elements of a packaged diode degrade the general performance of limiting and switching at the frequencies of interest. Furthermore, the parasitic elements can be essentially eliminated or considerably reduced by removing the diode from the package and integrating it directly into the waveguide transmission line.

Work reported in the second quarterly report on packaged PIN diode performance shows the bandwidth characteristics of the circuit where

additional reactances must be used to tune out diode package reactance. This results in a narrowing of the bandwidth of operation when compared to integrated diode designs.

An important advantage of the ridge waveguide and integrated PIN diode design is the inherent bandwidth. The bandpass characteristic of the ridge waveguide structures without diodes was shown and discussed in the last quarterly report. Work has progressed to actual performance data of switching over a broad bandwidth.

Three narrow (.021 inch) ridge and one wide (.084 inch) ridge waveguide structures have been fabricated. In addition parts for testing single and dual diode circuits have been obtained. Figures 6 and 7 show the general form of these experimental sections.

Initial tests with the single diode circuit yielded insertion loss .7 db, isolation 16 db and VSWR 1.24. This data is plotted in Figure 8. The performance of the diode circuit is a function of the RF choke, as well as the diode, and the choke lengths must be empirically determined in order to secure an optimum design. Therefore, several sets of parts have been machined to provide variation in either the high or low impedance choke sections. Tests have been conducted to evaluate the choke lengths and provide information with which a theoretical analysis may be applied.

Intuitively it can be seen that the choke will effect the circuit in both the insertion loss case, by leakage loss in the circuit, and in the isolation case by introducing a small but finite reactance in

series with the diode, this can then create an ineffective short.

The integrated structure does show some parasitic reactance and the choke provides the tuning. The integrated diode characteristics are not completely known at this writing and future efforts are to be directed toward evaluating these characteristics and the diode mounting methods.

Work was also performed with a dual diode circuit. Measurements have been recorded over a bandwidth from 22 to 24.5 gc. Figure 9 shows that the first switch was quite successful, maximum insertion was 1.4 db, minimum isolation 28.4 db and maximum VSWR 2.1.

This unit was measured under high power conditions in increments from 50 watts to 1.0 kilowatts peak. Isolation was measured as a function of the forward D.C. bias applied to the diodes. Forward bias is used to accomplish isolation because the diode appears as a very low shunt resistance across the transmission line. This results in minimum power dissipation in the PIN junction and thereby increases its power handling capability. Under actual operating conditions this bias would be supplied by a crystal rectifier in the circuit which would couple energy from each RF pulse to bias the diode. Because of the finite switching time of the diode the isolation achieved by this method would be lower than that shown on the curves for the D.C. bias condition. A 20 nanosecond pulse (as used in this application) dictates the need for extremely fast switching diodes.

Figure 10 shows data taken during the high power tests. Isolation

is plotted as a function of foreward D.C. bias for each power increment. After the 1 KW measurement the unit was tested at low power levels and no degradation was indicated due to high power.

These tests on single and dual diode switching are preliminary efforts, actual limiting measurements are planned for future work.

Present methods of integrating the PIN junction to the ridge waveguide structure have not been completely successful. The diodes have been subjected to mechanical stress beyond endurance and in some instances are destroyed in assembly.

Several approaches to this problem have been discussed in which a spring structure is incorporated into the ridge waveguide. Another approach is in the construction of the diode where a process called thermal compression bonding seems to give the best results in diode assembly. New designs will be evaluated in the next period.

4.3 Ferrite Limiter Effort

Several ferrite materials and configurations have been investigated in a test jig illustrated in Figure 11. The advantage of this type mount were presented in the last quarterly report. Three series of tests have been performed on the ferrite limiter with the following results.

TEST 1

Three units were fabricated using a YIG (G-113)* ferrite material

* Manufactured by Transtech Inc. Maryland

ground to different lengths but maintaining the same shape and width. These units were tested under high and low power conditions at various levels of applied D.C. field. The unit with the longest ferrite piece showed favorable isolation characteristics but had excessive insertion loss. VSWR at the test frequency (24.0 KMc) is 1.52:1 so its contribution to the total insertion loss may be neglected.

It may be seen in Figure 12 that the threshold for limiting is below 500 W peak, exact measurements of the threshold level were not taken. However, it may be seen that limiting in excess of 16 db occurred at power levels from 500 W peak to 2800 watts peak. At 2800 watts peak partial saturation of the spin wave structure has occured as may be inferred from the reduction in isolation from 24 db to 20 db at 2.8 kw peak.

TEST 2

Two units were fabricated using a sample of supposedly low loss polycrystalline YIG ferrite material ground to the same size as the two longest units previously tested. Preliminary results showed even higher insertion loss values, (4 - 6 db) therefore, further planned testing was discontinued.

TEST 3

A single unit was fabricated using the original YIG (G-113) ferrite material ground to a shorter length than those previously tested but with increased width to induce higher isolation by increased interaction with the R.F. field. Insertion loss of this unit is 3.5 db.

High power testing has not been performed on this unit as yet. These tests will be conducted as in Test 1 with additional effort to determine the threshold of limiting.

Further effort to achieve similar limiting action in either a shorter length or at less insertion loss will be continued in the next quarter.

4.4 Multipactor Efforts

Two important potential physical characteristics of a multipactor limiter are extremely fast recovery time and the possibility of long life because of the absence of gases. During this period, a test cavity was designed and constructured for evaluating different multipactor surfaces and design of the multipactor limiter was initiated.

The last report briefly discussed the nature of the multipactor discharge. To evaluate the discharge characteristics, i.e., obtain the volt-ampere curve, an X band cavity with replaceable pole pieces was constructed. The structure is shown schematically in Figure 1 and represents a more versatile modification of our earlier design discussed in the last report. The cavity consists of a waveguide body with windows attached and the secondary emission surfaces, under study, are situated on the faces of the pole pieces. Vacuum sealing is accomplished by means of annealed OFHC copper gaskets pressed onto knife edges. The gap is brought into resonance with irises external to the vacuum.

Several multipactor discharges were produced in this structure with a phosphor which has good secondary emission properties; however,

our initial surface preparation did not field the desired characteristics and the experiments were hampered by difficulties with window failures. Better results are expected from improved techniques.

A second type of secondary emitting surface using silver magnesium alloy is also being readied for testing. It has been necessary to develop a technique for bonding the thin sheet of alloy to the pole pieces. The bond must be able to withstand a high temperature because the surface activation process requires temperatures in excess of 700°C. The bonding technique involves a gold diffusion process and when properly activated, this type surface results in excellent secondary emission properties.

A structure for the multipactor limiter has been designed and construction is in process. The basic design is shown in Figure 14. The object is to obtain regions of different heights in order to extend the dynamic range of operation and take advantage of higher order multipactor modes. In the final version, the basic structure can be modified to be resonant and reduce the threshold of operation thus increasing dynamic range of operation at the expense of bandwidth.

In the next interval we will complete evaluation of surface processing and obtain data on the multipactor limiter characteristics.

V CONCLUSIONS

All phases of the work in this contract have advanced to the point where hardware designs are available. Tests performed have indicated some success in each area.

In the gas TR work three tubes were fabricated, two units were exhausted and measured with and without keep-alive. The third unit was not exhausted and was used for spark gap R.F. breakdown experiments. The semiconductor switch limiter work has been carried to the point where a two PIN diode integrated structure has been measured successfully at 1.0 kilowatts peak incident power with DC bias. Several ridge waveguide switch limiter test fixtures have been completed and low level power measurements have indicated the design to be satisfactory for application toward the design goals for this contract.

The ferrite circulator design is completed.

Some success is reported on the ferrite limiter. High insertion loss (3.4 db) is a major obstacle at this time.

The multipactor work has been directed toward determining satisfactory surface materials and preparation techniques. Some tests have shown multipactor discharge, however, desired characteristics have not been achieved.

VI PROGRAM FOR NEXT INTERVAL

During the next quarterly report period, work will be evaluated and a final technical approach decision will be made early in the period.

A brief description of the work planned for the period is as follows

(a) Two more gas TR tubes will be fabricated and measured. Life tests will commence during this period.

(b) Switching time and recovery time of the integrated diode structures will be measured as well as switched limiting.

Better methods of diode mounting will be determined to reduce assembly damage.

(c) The ferrite circulator will be life tested.

(d) The efforts on the ferrite limiter will be to reduce the insertion loss and complete high power tests.

(e) The evaluation of surfaces will be completed and a multipactor limiter will be measured.

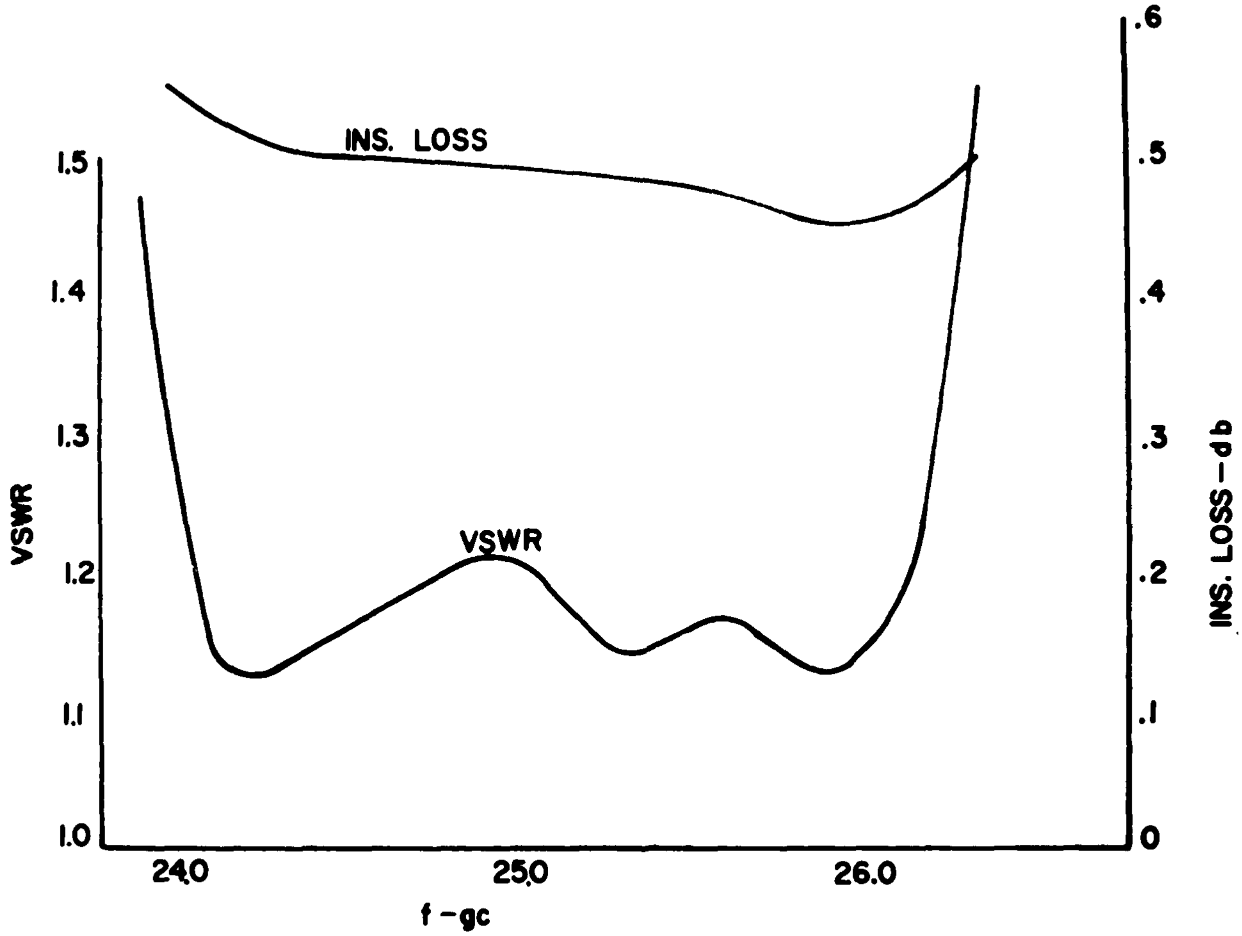
VII IDENTIFICATION OF KEY TECHNICAL PERSONNEL

The following key personnel contributed to the quarterly period covered by this report.

Name	Title	Hours
Dr. K. Mortenson	Physicist (Director Research & Development)	3
R. Tenenholtz	Microwave Engineer (Group Leader)	164
*R. Brunton	Microwave Engineer	54
S. Segal	Microwave Engineer (Group Leader	62
H. Mooncai	Microwave Engineer	46
R. Whitney	Engineering Assistant	413
*P. Basken	Microwave Development Engineer	105
C. Howell	Semiconductor Engineer	6
Dr. M. Gilden	Senior Engineer - Tube Division	57

*Biographies of these personnel are included in Appendix A. All others have been previously presented.

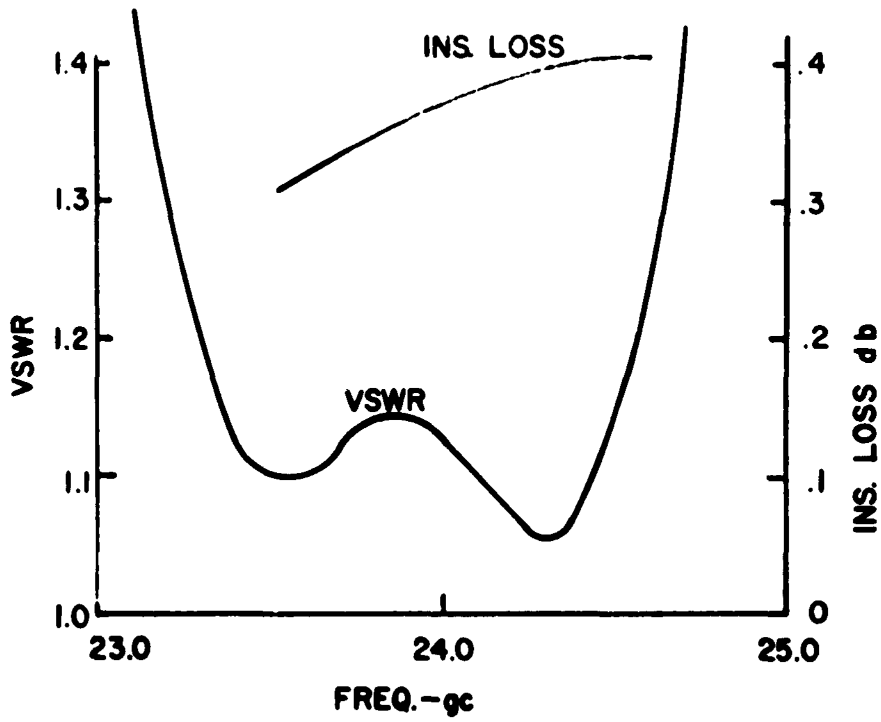
VIII LIST OF ILLUSTRATIONS



K BAND TR KI (3 ELEMENT)

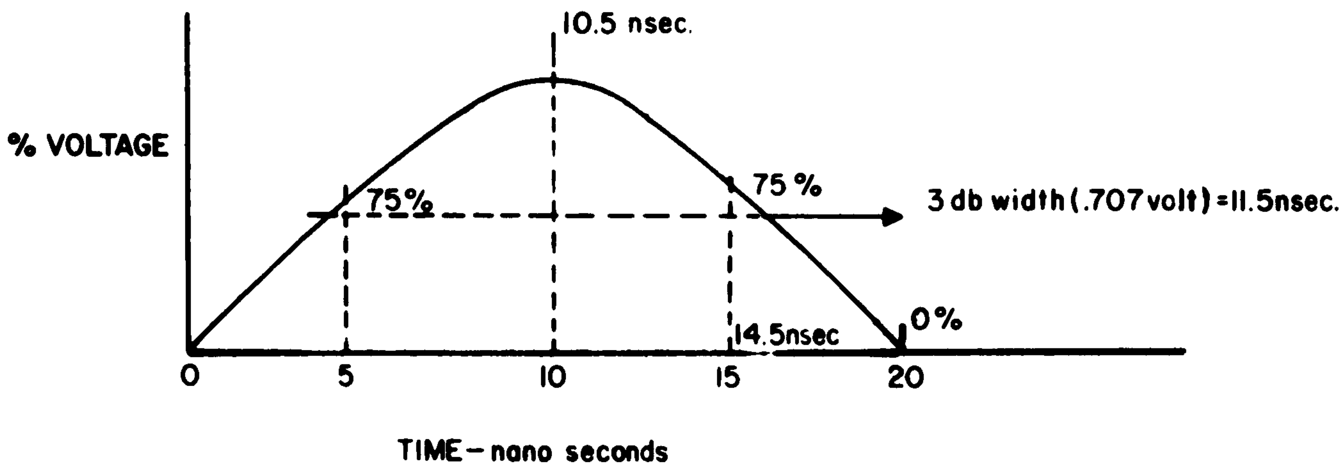
Q OF CENTER ELEMENT	6
Q OF WINDOWS	3
ELEMENT SPACING	240°

FIGURE 1



K-BAND TR 010 (3 ELEMENT)
Q OF CENTER ELEMENT 3.8
Q OF WINDOWS 3
ELEMENT SPACING 240°

FIGURE 2



prr = 15 Kc, $tp_3 db$ = 11.5 nsec., du = .000173

INCIDENT PULSE ON SAMPLING SCOPE
FIGURE 3

TUBE MEASUREMENTS

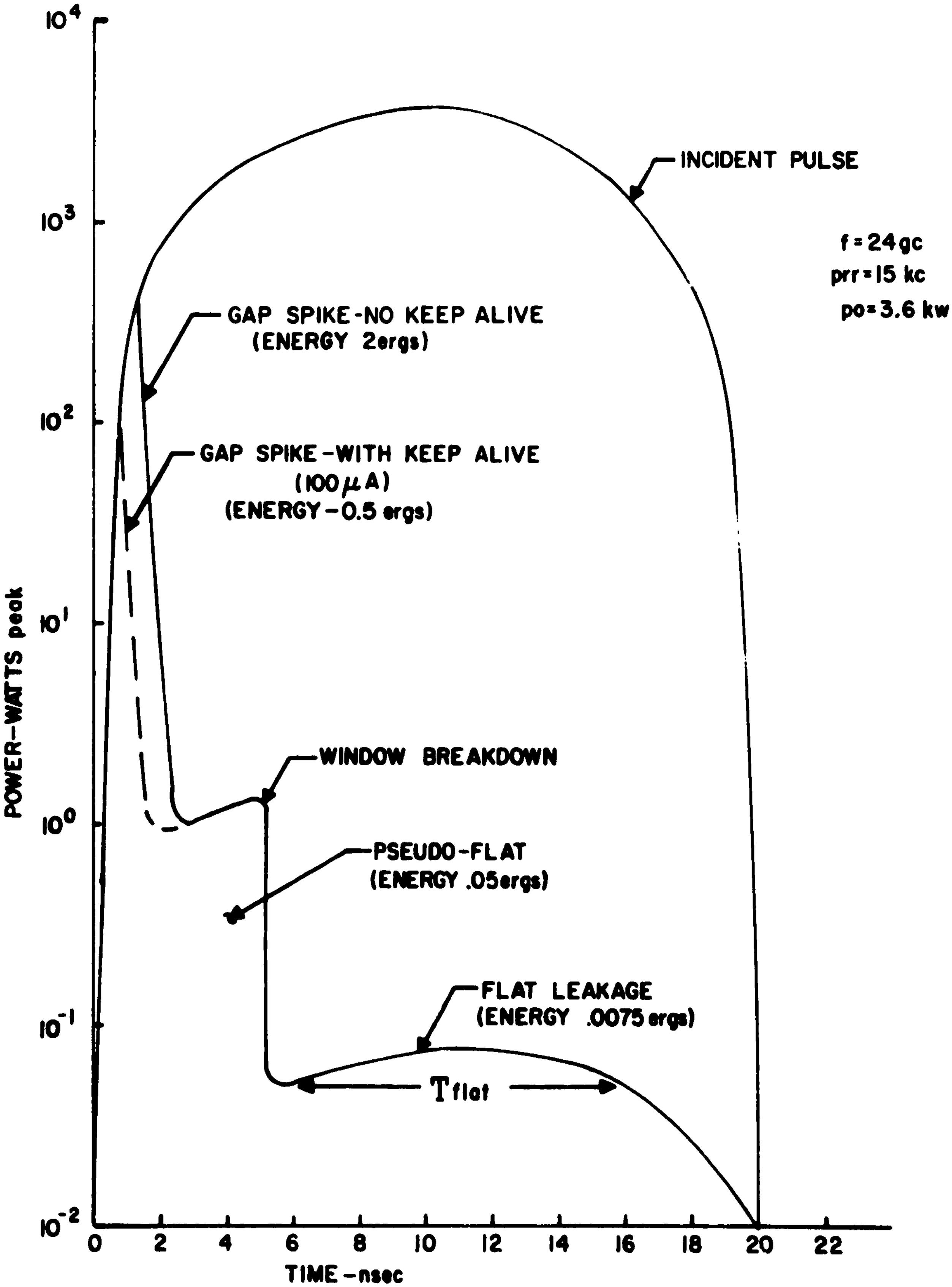
Po = 3.6 Kw , PAVE = .62 watts

TUBE	KEEP ALIVE CURRENT	Pspike — w Sampl. Scope	T_s 3db-ns	Ws-ergs $10^{-7} P_s T_s$	Pave-mw bridge	Pf-mw Scope	Ws-ergs $10^{-7} \frac{Pave}{prr}$	RT 3db nsec.
010	0	400	.5	2 erg	3.0	75 mw	2 erg	180
"	100μA	100	.5	.5 erg	.86	75 mw	.58 erg	190
K-1	0	300	.4	1.2 erg	1.55	57.5 mw	1.04 erg	180
"	100μA	50	.4	.2 erg	.4	57.5 mw	.26 erg	180

NOTE: FLAT LEAKAGE WIDTH .010μ sec., THEREFORE ENERGY IN FLAT ONLY .0075 ergs max.

FIGURE 4

FIGURE 5
K BAND PRE. TR. SN 010
INICIDENT AND LEAKAGE PULSE ENVELOPES



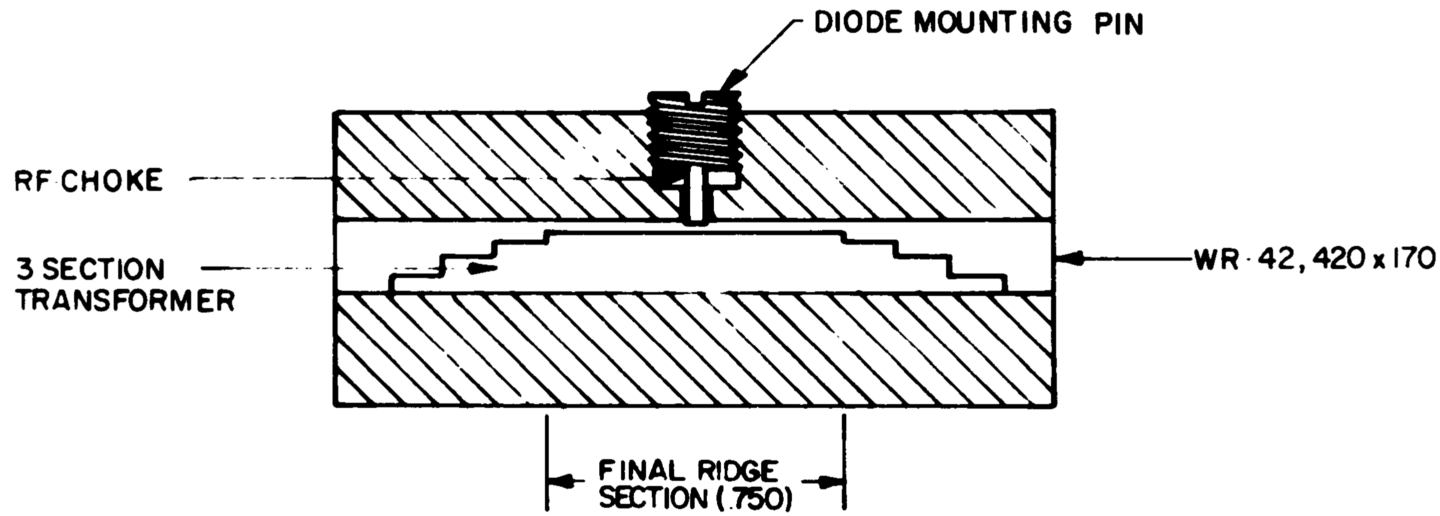


FIGURE 6
SMALL GAP RIDGE WAVEGUIDE SECTION
SINGLE DIODE MOUNT

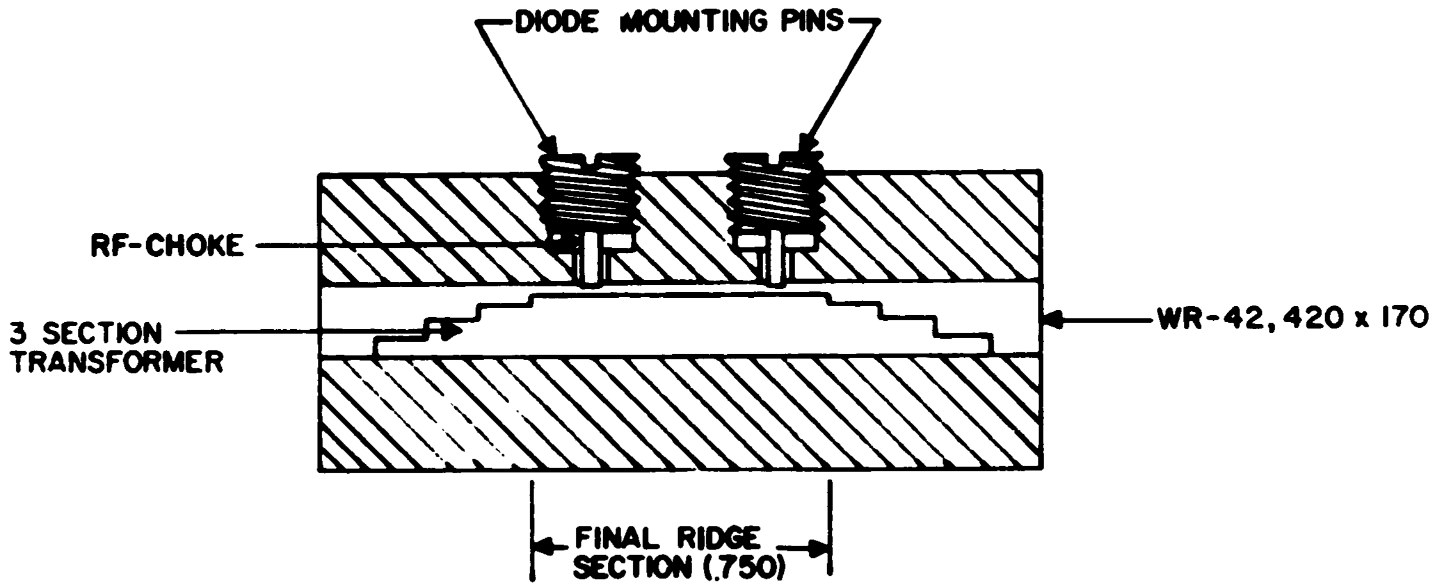


FIGURE 7
SMALL GAP RIDGE WAVEGUIDE SECTION
DUAL DIODE MOUNT

INTEGRATED SINGLE DIODE K BAND SWITCH
PERFORMANCE AT LOW LEVEL INCIDENT POWER

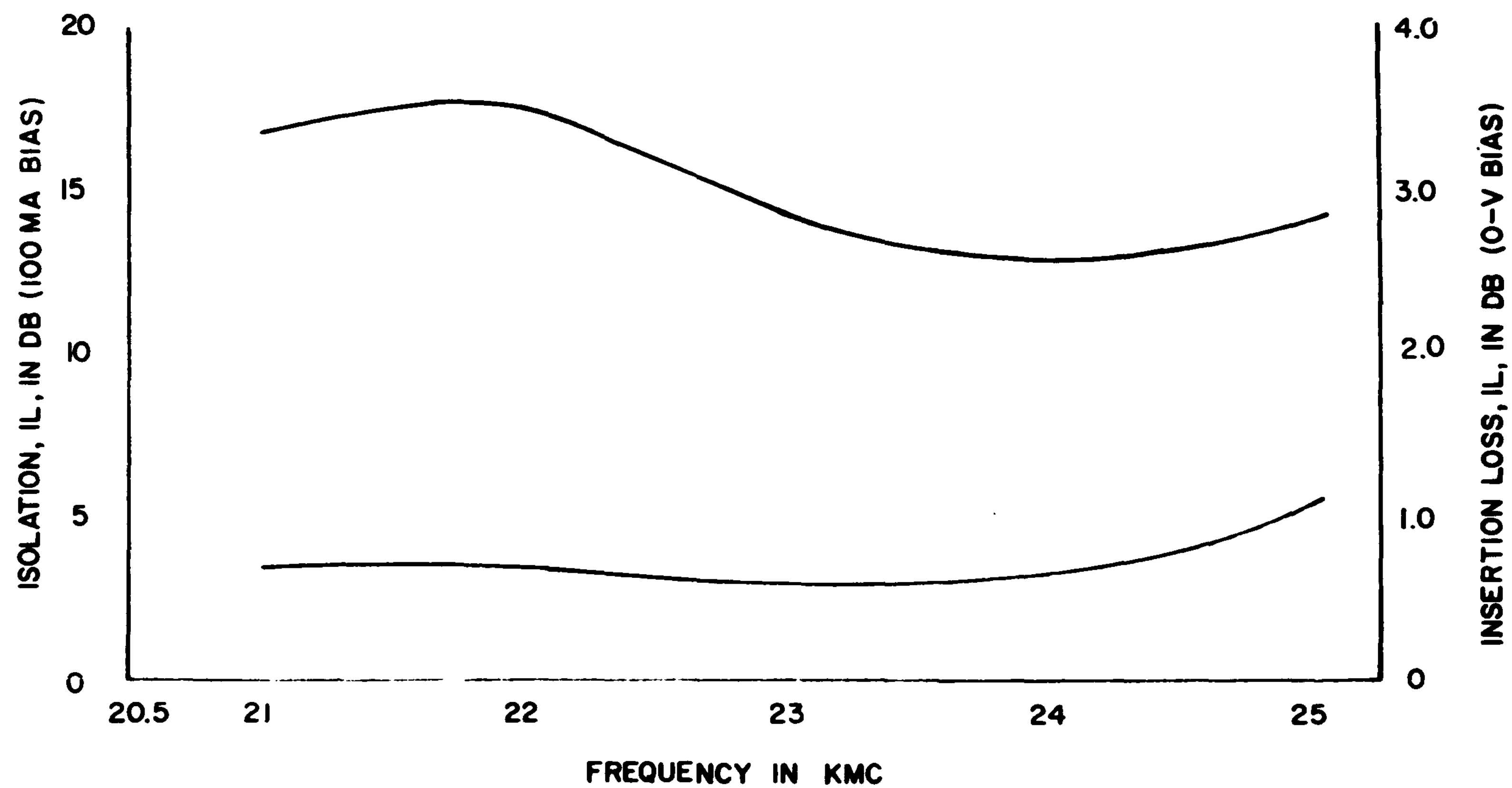


FIGURE 8

INTEGRATED DUAL DIODE K BAND SWITCH
PERFORMANCE AT LOW LEVEL INCIDENT POWER

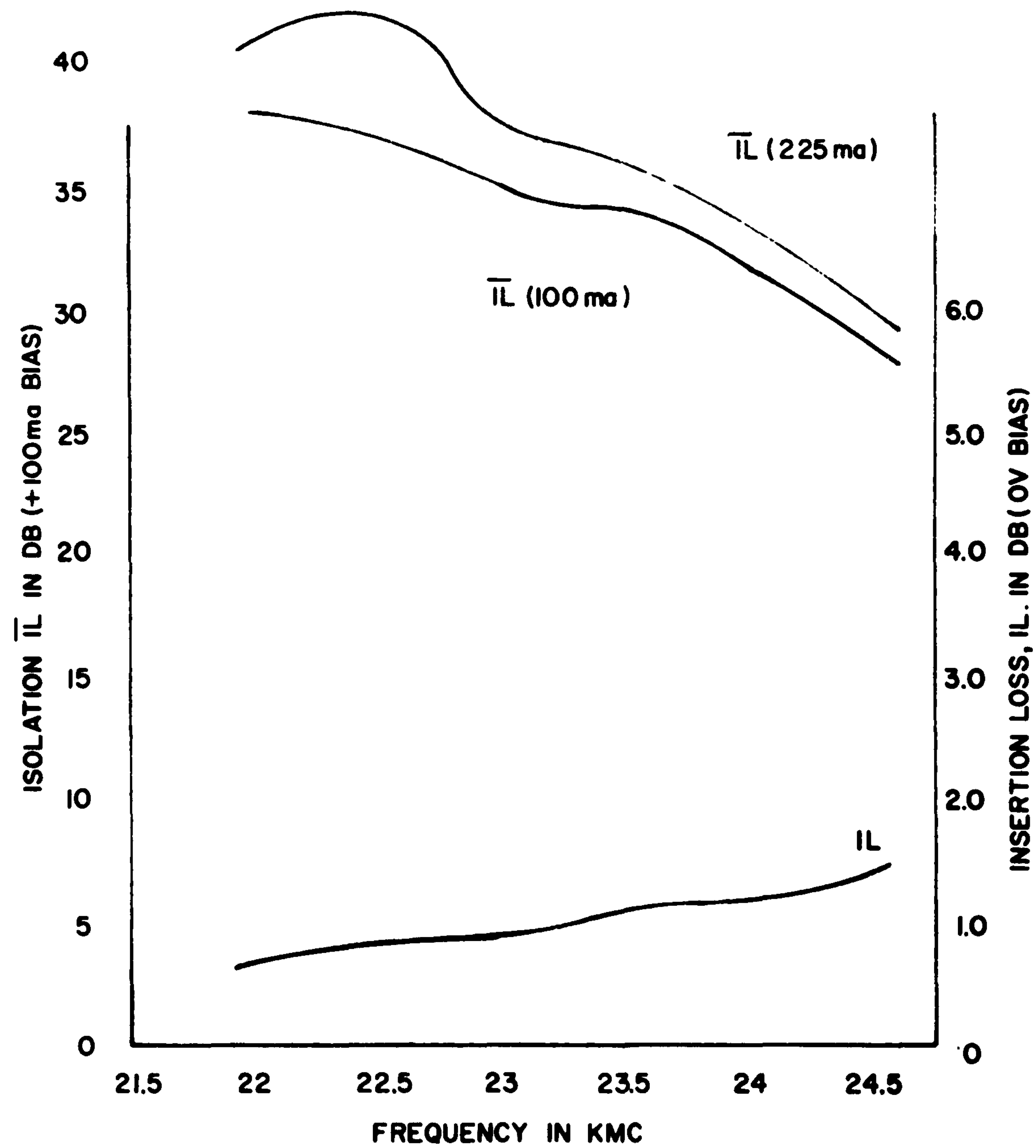


FIGURE 9

INTEGRATED DUAL DIODE K-BAND SWITCH
ISOLATION AT 50 TO 1000 WATTS PEAK INCIDENT POWER

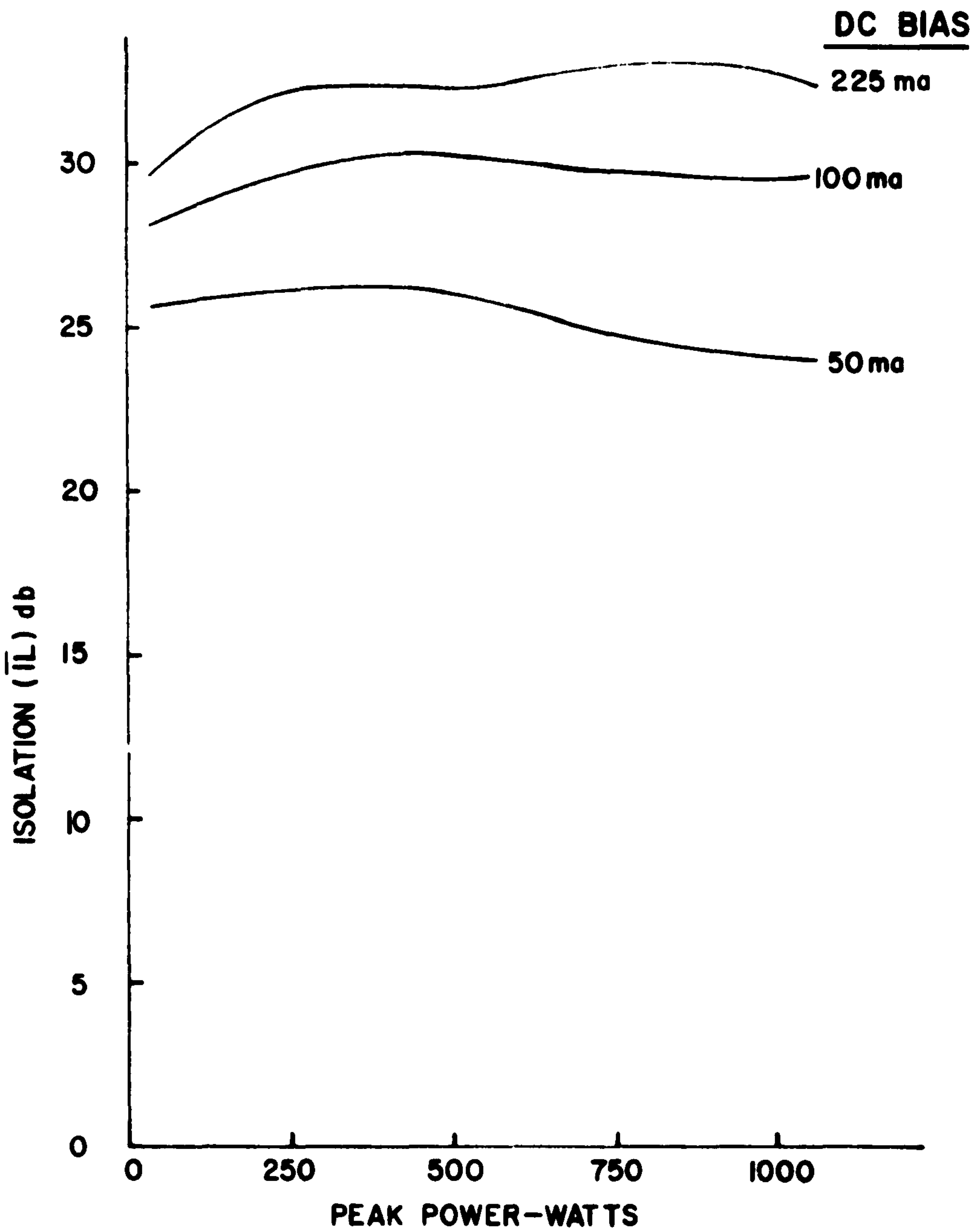


FIGURE 10

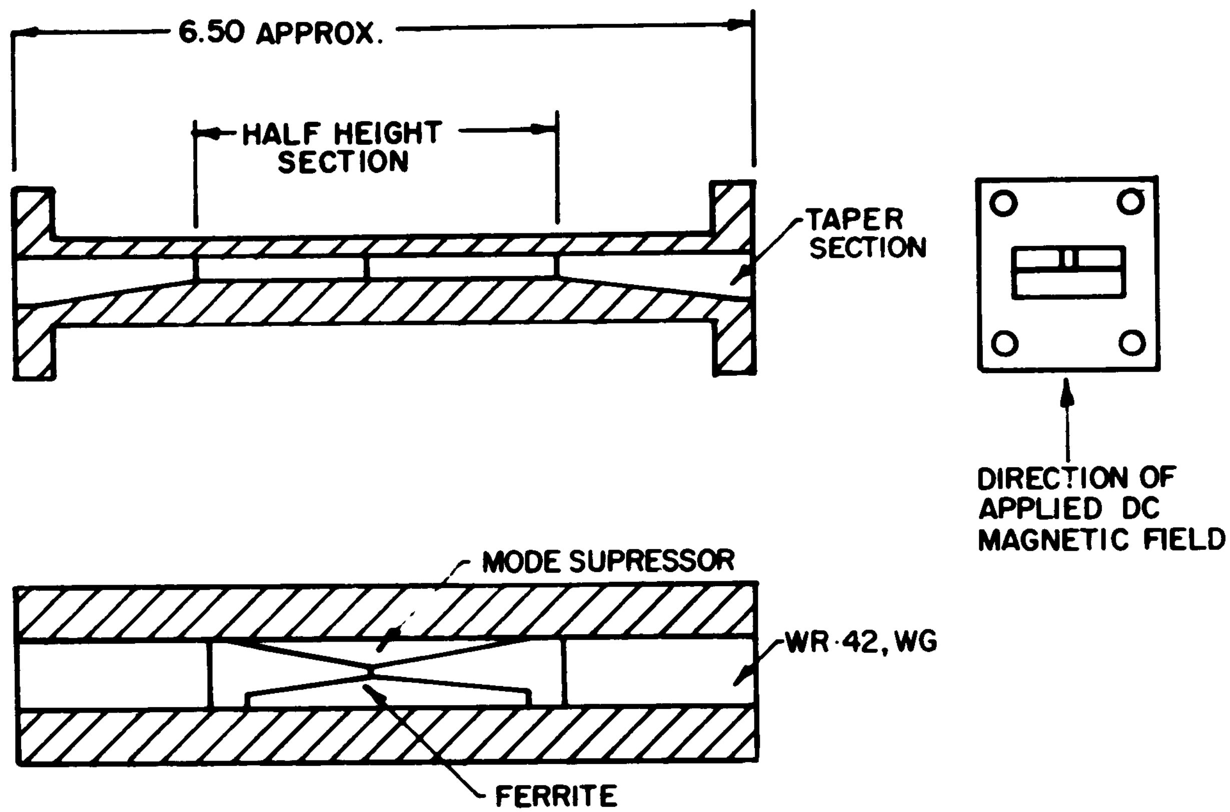


FIGURE II
K-BAND FERRITE LIMITER ASSEMBLY

K BAND FERRITE LIMITER PERFORMANCE
AT DISCRETE INCIDENT PEAK POWER LEVELS

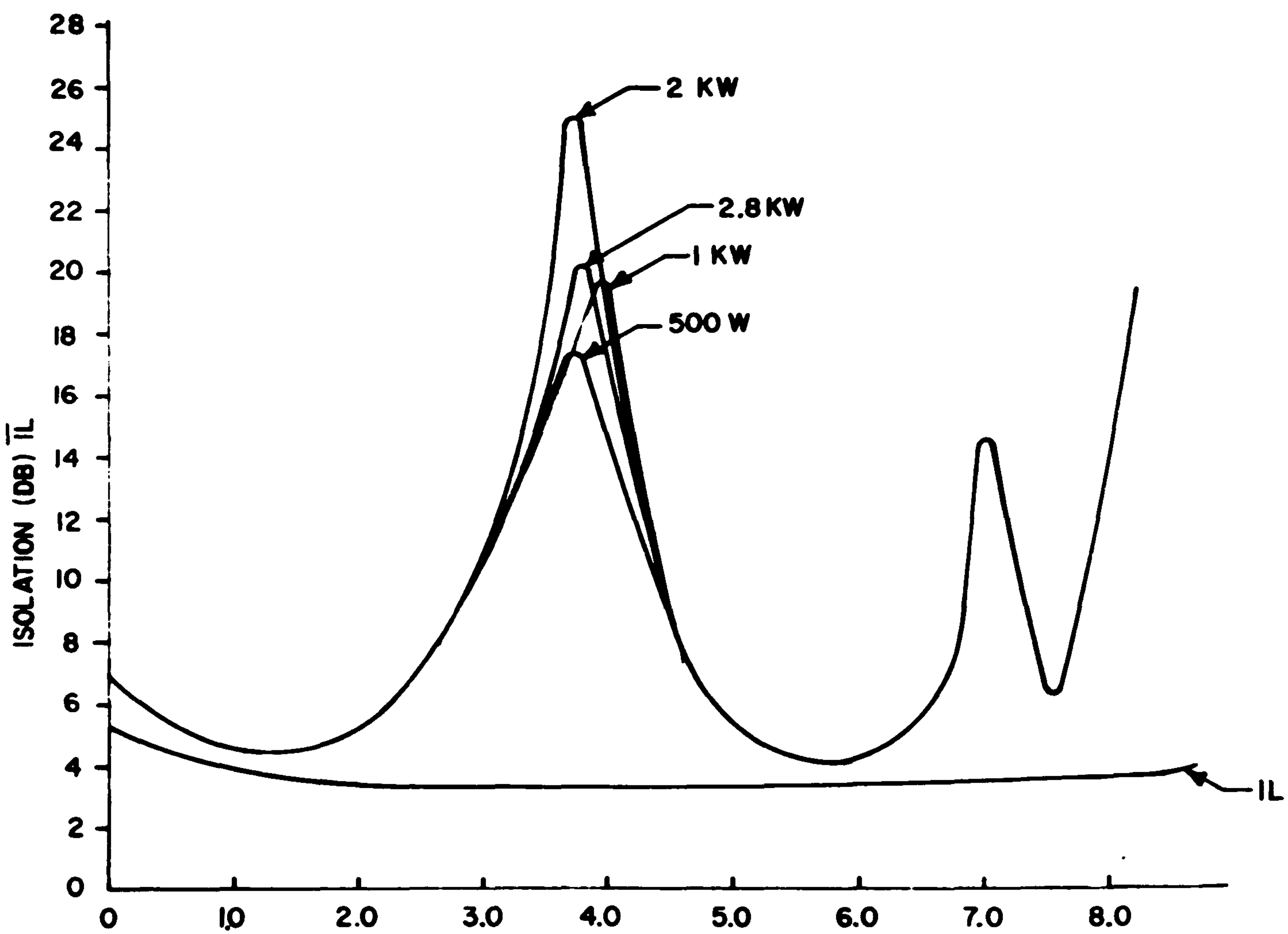
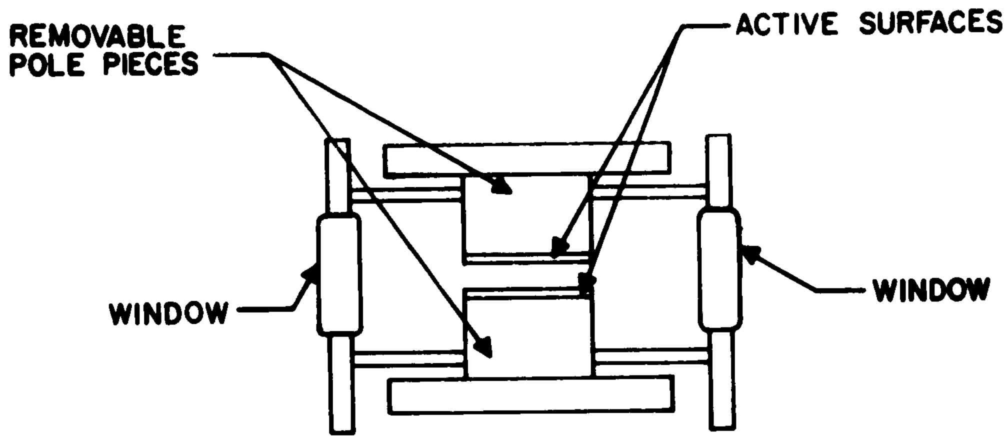
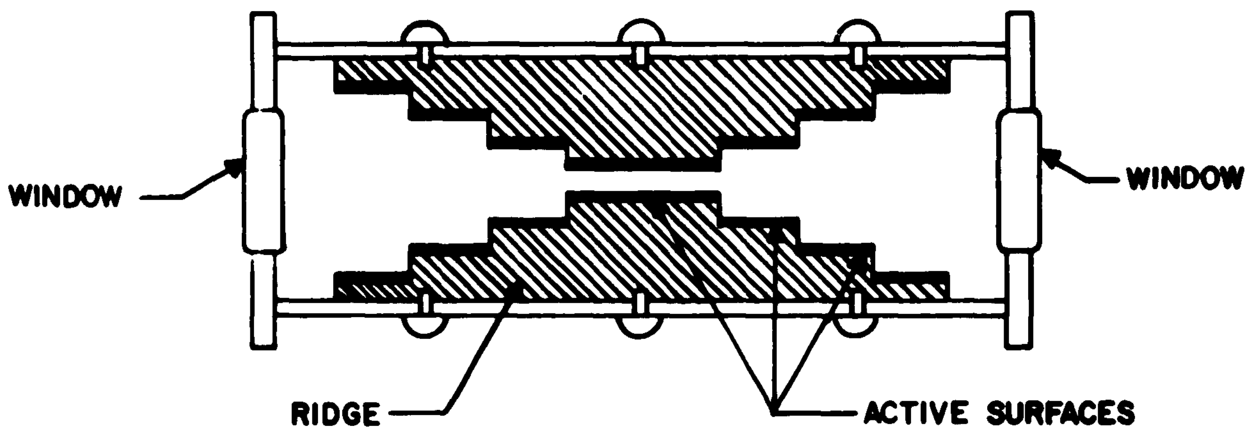


FIGURE 12



SURFACE EVALUATION CAVITY
FIGURE 13



MULTIPACTOR LIMITER
FIGURE 14

APPENDIX A

Robert H. Brunton

Mr. Brunton attended Newton Junior College and Lincoln Technical Institute and received his Associates Degree in Electronics in 1958. In 1961 he obtained his BBA Degree from Northeastern University. His major was management in engineering. Since that time Mr. Brunton has taken various engineering graduate studies at Northeastern University.

Mr. Brunton was employed by Microwave Development Laboratories from 1949 to 1952. From 1952 to 1954 Mr. Brunton served with the U. S. Army.

He rejoined Microwave Development Laboratories in 1954 as a junior engineer. His work included experimental design of microwave components and packaging microwave subsystems. Mr. Brunton was project engineer and supervised production of temperature compensated wavemeters at M.D.L.

In april 1957 Mr. Brunton became employed at the Radio Corporation of America, Airborne Systems Laboratories. His duties included development of stable local oscillators, and evaluation of traveling wave tubes for both the receiver and transmitter system for a doppler radar. From November 1957 to January 1959, Mr. Brunton joined a team of R.C.A. engineers to perform systems evaluation of the U. S. Air Force GRA-5 time division digital data link ground to air communications system.

Mr. Brunton Joined the Advanced Development group at R.C.A., Burlington, January 1959. As a senior member of the technical staff, his duties consisted of design of microwave radiometers, application of parametric up-converters to phase array technique and design of solid-state mircowave switching devices for modulation and attenuation in systems. He was res-

ponsible for the design and construction of two discreet electromagnetic environmental simulation systems.

During the period of January 1962 through March 1963, Mr. Brunton was employed by the Ewen Knight Corp. and Sage Laboratories. His duties involved the design and supervision of a microwave radiometer system using tunnel diodes and other solid-state components. Also, he was responsible for the development of single side band modulators, many complex microwave packages and microwave components.

In March 1963, Mr. Brunton joined Microwave Associates as a group leader in the field of solid-state microwave devices.

Mr. Brunton is an Associate Member of the IEEE and PTGMTT.

Paul Basken, Engineer

Mr. Basken completed three years at the University of Connecticut in 1959 majoring in mathematics and physics. He joined Microwave Associates in 1959 and is a development engineer working on the design and development of various microwave gas switching tubes at frequencies up through 35 KMc. He has been concerned with problems of gas processing control and the nature of the gas fill on the electrical characteristics of the tubes, fabrication of precision parts for millimeter TR tubes, and microwave theory and testing techniques.

AD ______ Accession No. ______

MICROWAVE ASSOCIATES, INC.
BURLINGTON, MASSACHUSETTS

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R. Tenenholtz, R. Brunton

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31 pp. - Illus. Signal Corps Contract No. DA-36-039-SC-90834

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Technical achievements in this period are discussed in the technical section of this report.

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BURLINGTON, MASSACHUSETTS

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